

RESEARCH DEPARTMENT

COLOUR TELEVISION:
THE ADAPTATION OF THE N.T.S.C. SYSTEM TO U.K. STANDARDS

PART 2: A COLOUR TELEVISION FILM AND SLIDE SCANNER

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PART 2: A COLOUR TELEVISION FILM AND SLIDE SCANNER

1. INTRODUCTION.

A film and slide scanner for colour television does not differ fundamentally from its more familiar counterpart in the conventional black-and-white television system. The electrical signals which it produces must, however, not only be related to the brightness of objects in the scene but must also describe their colour with satisfactory accuracy.

This report will deal with the design of a flying-spot scanner to produce red, green and blue colour-separation signals as part of a complete system of colour television.

2. DESIGN CONSIDERATIONS.

The design of the film and slide scanner was influenced to a large extent by the fact that it was intended only as laboratory apparatus required for subjective and other investigations into methods of transmitting colour signals. There was no necessity for many of the minor facilities usually associated with operational equipment and therefore the apparatus was made as simple as possible.

2.1. Film Gauge and Pulldown Angle.

It was decided to use 16 mm film as the source of motion pictures despite the fact that the average picture quality obtained from this gauge of film is not adequate to do full justice to a 405 line television system. The choice was influenced by the relative ease of providing a suitable intermittent film transport mechanism with the short pulldown time which is standard practice in 16 mm projectors but is not available in 35 mm machines.

In the British 405 line television waveform the interfield suppression period is 14 lines which represents a pulldown angle of 12.4° in an intermittent film transport mechanism.

Considerable effort has been expended by the radio and cinematograph industries in an endeavour to produce a quick pulldown intermittent mechanism to perform this function satisfactorily, but few such devices are available and most telecine machines employ continuous-motion mechanisms^{1,2,3,4,5}, or image storage techniques^{6,7}. For the purpose of colour-television system appraisal it was not considered necessary to adopt such elaborate methods and a standard commercial 16 mm projector mechanism would be used (GB-Bell and Howell Model 609).

This machine has a pulldown angle of 40° and it is therefore not possible to scan the whole of each film frame since the film is still moving during part of the active television field period. The total loss with a 40° pulldown is 90 lines, but of this 28 are normally suppressed (two interfield periods) so that the total loss of active picture is approximately 16.5%.

The pulldown mechanism is so phased with respect to the television waveform that the picture is blanked equally at top and bottom by 31 lines, and though this loss is noticeable, it is by no means objectionable. It is, incidentally, less than the loss of picture area now practised by the cinema in the current "wide screen"

projection, which in many cases is achieved by masking nearly 20% of the height of the standard film frame to change the aspect ratio from 4:3 to 1.66:1 and then using a projection lens of shorter focal length to produce the desired effect.

A standard Bell and Howell mechanism is being modified to give a pulldown angle of 25° and if this is successful the loss of picture area will then be only $3\frac{3}{4}\%$ (14 lines) at the top and bottom of the picture.

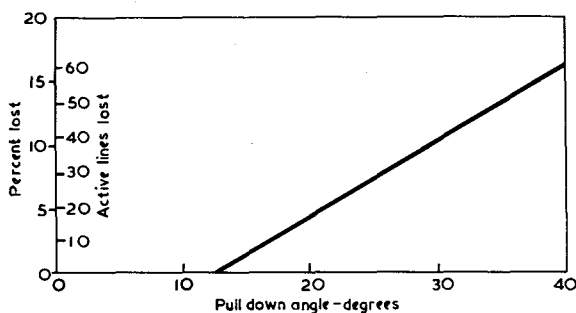


Fig. 1 - Loss of picture due to pulldown time

2.2. Sensitivity.

It was stated at the beginning of Section 2.1 that 16 mm film quality is not always adequate for 405 line television, and it is perhaps worth while elaborating this point.

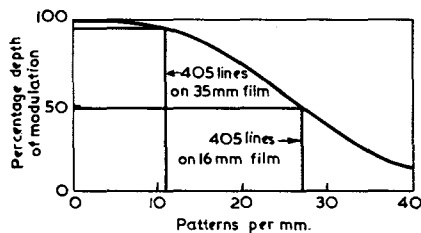


Fig. 2 - Loss of contrast by the film

Fig. 2 shows a curve of the percentage modulation which may be impressed upon a typical black-and-white negative emulsion for various degrees of required definition, represented by test patterns of alternate black-and-white vertical bars.

Where a very coarse pattern is photographed the contrast between blacks and whites is taken to be 100% but when the pattern becomes finer the contrast recorded on the film falls until a point is reached where the film is unable to record the detail at all. On 35 mm film the equivalent of a

3 Mc/s signal suffers a loss of about one decibel whereas the same signal recorded on the smaller frame of 16 mm film suffers a loss of six decibels. The 16 mm scanner therefore has a disadvantage of at least five decibels at 3 Mc/s due to the shortcomings of the film which is it required to scan.

It is however in the design of the optical system for a 16 mm flying spot scanner that the limitations of this gauge of film become most apparent. The random noise output current of a photocell varies as the square root of the photo-cathode

current so that where the total light flux falling on the multiplier photocell of a flying-spot scanner is low, the signal-to-noise ratio of the output signal is also low and can only be improved by increasing the level of the light which reaches the photo-cathodes after passing through the film and so becoming modulated.

In the calculation which follows it will be shown that apart from the brightness of the flying-spot itself, the modulated light available is a function only of the solid angle subtended at a point in the object plane by the entrance pupil of the lens. This solid angle is, of course, a function of the f /number of the lens used but it is also a function of the degree of magnification being used, i.e. the ratio, image size/object size

$$\left(\frac{v}{u} \right).$$

In a photographic camera the emulsion takes note only of the brightness of the image formed, and the effect of light falling upon any small area of the emulsion remains the same whether that area represents the whole image or only a small part of a very large image. In a flying-spot scanner, the output signal current is proportional to the total modulated light flux reaching the photocell and is therefore a function of the area of the image formed as well as the brightness of that image, i.e. it is a function of the magnification of the optical system.

In Fig. 3, A is the area of the entrance pupil of the lens, and it subtends a solid angle Ω at a point in the object plane. The object and image distances are u and v respectively. The total light collected by the lens will be proportional to Ω , and if Φ is the luminous flux thus collected,

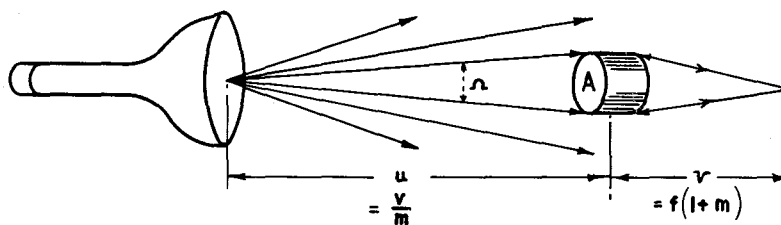


Fig. 3 - Light collection by a lens

$$\Phi = \frac{KA}{u^2}$$

where K is a factor proportional to the brightness of the flying-spot.

The output signal current from the photocells, $W \propto \Phi$, hence

$$W \propto \frac{KA}{u^2} = \frac{KA m^2}{f^2(1+m)^2}$$

where m is the magnification of the system and f is the focal length of the lens. But

$$\frac{A}{f^2}$$

is a constant for any given f /number regardless of the focal length of the lens.

It follows that

$$W \propto \frac{m^2}{(1+m)^2}$$

It is therefore important in designing a flying-spot scanner that the magnification should be made as large as possible, and it is here that the disadvantage of the narrow gauge film is most apparent, because the limitation of sensitivity lies mainly with the flying-spot tube. Considerations of spot size and phosphor saturation place a lower limit on the size of the scanning raster which can be used, and this in turn fixes the maximum magnification which can be employed in the optical arrangements.

2.3. Slide Scanning Facilities.

It was decided that a flying-spot scanning raster 3 in. \times 2 $\frac{1}{4}$ in. (7.6 cm \times 5.7 cm) represented a reasonable compromise between resolution and phosphor saturation due to spot size on the one hand, and on the other the necessity of making the magnification of the optical system large. A flying-spot raster of this size requires magnification of $\frac{1}{8}$ when used to scan the 16 mm film frame, which gives (from the formula above) a light factor of only $\frac{1}{81}$ compared with $\frac{1}{4}$ had it been possible to make the raster as small as a 16 mm film frame and hence, $m = 1$.

In order to have available an additional source of television pictures in which the signal-to-noise ratio is as good as possible, the scanner was also arranged to accept large still-frame colour transparencies as subject matter. The size of the scanning raster suggested convenient dimensions for the transparencies, and the standard 3 $\frac{1}{4}$ in. (8.3 cm) square lantern slide was chosen; these are masked to a useful picture area of 3 in. \times 2 $\frac{1}{4}$ in. (7.6 cm \times 5.7 cm) which makes $m = 1$. With twenty times more light flux than the 16 mm frame, signal-to-noise ratio would be expected to be 13 dB better, and with lenses of equal f/number this figure can be achieved in practice.

As an additional facility, provision was made to accept also 24 mm \times 36 mm slides as subject matter; here of course the signal-to-noise ratio falls between those of the two sizes mentioned. This "Leica" size has the merit that a variety of ready-made slides is available commercially.

2.4. Video Equalisation.

As is well known, resolution and noise level in a television picture can be exchanged by passing the video signal through an equalising network of suitable characteristics. In an ideal, noise-free, television system it would be possible to equalise completely all losses of horizontal resolution, but under practical conditions the noise level usually limits the extent to which equalisation may be applied. Where the loss of resolution cannot be compensated before the introduction of the noise (i.e. before the photomultiplier in the case of the flying-spot scanner) equalisation of the signal spectrum must result in the noise becoming accentuated with consequent increase in annoyance value.

Losses of resolution in a film scanner are mostly due to the afterglow of the phosphor used in the flying-spot tube, but also contributing are the lens and the

reduced modulation in fine detail due to the film itself. Loss due to afterglow is a constant for any given tube operated at fixed beam current, and is therefore corrected separately by pre-set "afterglow-correcting" networks², but the other losses will obviously change when the size of the film or slide is changed.

The amount of correction required for the effects of afterglow is dependent on the shape of the decay characteristic of the afterglow and its duration. When the flying-spot scans a pattern of fine detail, for example, 3 Mc/s bars, the signal derived from the photomultiplier is a function of the depth to which the total light falling on the photocell is modulated at the pattern frequency, whilst the noise generated is proportional to the square root of the absolute values of the light flux. If the flying-spot has an appreciably long afterglow of substantial brightness, the depth of modulation of the upper video frequencies will be low since the effective scanning aperture is greatly enlarged, while the high level of unmodulated light due to the integrating effect of the "trail" produces a high noise level. In electrical terms, the a.c. component of the light produces both signal and noise, while the d.c. component produces noise only, and the shorter the afterglow the greater is the a.c./d.c. ratio. Short afterglow is thus a very important factor in improving signal-to-noise ratio, as is also the absolute brightness of the flying-spot, and nothing may be gained by improving one at the expense of the other.

Since the initial signal-to-noise ratio is low for the reasons already stated, any attempt to compensate fully other losses when using 16 mm film will result in an intolerable level of noise, and a compromise has to be made. On the largest slide size where the demand on the resolution of the photographic stock is very much less, less equalisation is necessary and with the better signal-to-noise ratio obtaining, such equalisation can be applied without noticeable increase in the noise level. It so happens that the amount of equalisation required on the large slides roughly coincides with the amount which can be tolerated on the smaller sizes and one setting of the equaliser adjustment is found to be suitable for all three types of subject matter.

An interesting feature of the design of a film scanner is the balance which can be made between horizontal resolution, vertical resolution and signal-to-noise ratio.

Given that afterglow has been corrected, there remain aperture losses due to the finite size of the flying-spot and to the aberrations of the lens, both of which degrade resolution not only along the scanning lines, but in all directions in the image plane. Since equalisation can operate only upon the horizontal resolution of a television picture, consideration must be given to the relative importance of vertical and horizontal resolutions⁸ and each possible improvement must be related to the cost in increased noise visibility. It will be noted that the application of spectrum equalisation⁹ does not in itself introduce noise; it is simply that poor signal-to-noise ratios existing in the upper parts of a frequency spectrum become more apparent when the amplitude characteristic has been corrected.

If horizontal resolution were the only important consideration, it might well be found advantageous to use the largest available lens aperture, regardless of loss of resolution, and then apply sufficient equalisation to make the resolution acceptable. Provided the signal level at the high frequencies is not actually reduced

when the lens aperture is opened, the noise in the picture may be given a reduced annoyance value, in that the low frequency noise becomes less and the high frequency noise is, at least, no worse. Cases have, however, been observed where the lens performance deteriorates so rapidly as the iris is opened towards full aperture that the signal level at frequencies above say 2 Mc/s actually falls despite the increase in light collection, and in such cases the overall result is of course degraded.

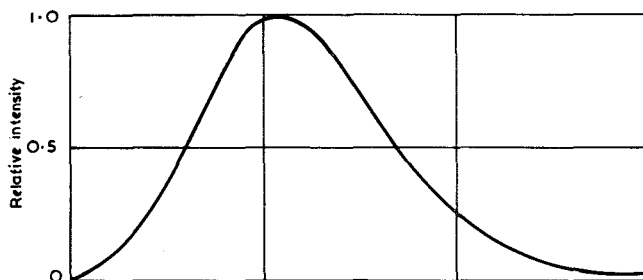
The foregoing, however, completely neglects resolution along the vertical axis of the picture, which has always been the "poor relation" of television. Clearly the number of scanning lines employed (405, 625, 819 etc.) sets an upper limit to the theoretical vertical resolution of a system but it is by no means true that the employment of a given number of lines will necessarily give that degree of vertical resolution*. Various estimates of the realisable vertical resolution of a 405 line interlaced raster quote values between 200 and 300 lines. This loss is beyond the control of the designer, but care must be exercised not to degrade the vertical resolution still further by the indiscriminate use of very large apertures for the improvement of signal-to-noise ratios which can then be exchanged for horizontal resolution. The problem is to decide by how much the picture may be allowed to become astigmatic before the unbalance is noticeable, or at what point a worsening signal-to-noise should stop further attempts to improve resolution. The work of M.W. Baldwin⁸ suggests that the ratio, horizontal:vertical resolution in a high quality television picture may be as much as $2\frac{1}{2}:1$ before the unbalance is noticeable to more than 25% of observers, so (provided the noise level permits) equalisation might be applied until this limit is reached, but if the noise level were still satisfactory any further improvements would have to be divided between both vertical and horizontal resolutions. Regrettably, in the present state of the art, the designer of a colour scanner seldom has this opportunity, but in the scanner described here it was possible to use a lens of aperture $f/3$ instead of $f/2$ on the largest size of slides.

2.5. Colour Analysis.

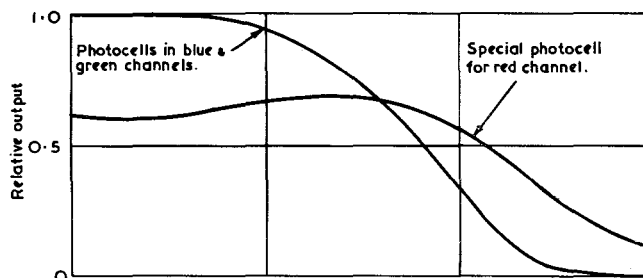
The spectral distribution of light from the flying-spot tube in a monochrome scanner is not of paramount importance because note is taken only of the intensity modulation of the light after it has passed through the film. In the colour scanner, however, note is taken of both intensity and colour modulation and it is therefore necessary that the output of the tube should have a continuous spectrum with substantial energy at all wavelengths of visible light. The ideal flying-spot tube phosphor would be one which had negligible afterglow and produced white light as a continuous spectrum of uniform energy. The most satisfactory phosphor so far available is zinc oxide which has a persistence sufficiently short to produce reasonable signal-to-noise ratios, though the spectral output is far from ideal: a curve is given in Fig. 4(a). The overall sensitivity of any particular colour channel is, of course, related to the product of the light output of the flying-spot tube and the sensitivity of the photomultiplier, integrated over the spectral range of the channel, and Fig. 4(b) shows the relative emissions of typical photomultiplier surfaces.

*It cannot be assumed that the use of a video bandwidth calculated on the basis of a square picture element will guarantee that the picture is not astigmatic. The resolving power of a raster of scanning lines can only be assessed on a statistical basis; it depends on the coincidence of the scanning lines with detail in the scene, on the stroboscopic effects due to an interlaced raster, and also on the periodicity of the brightness pattern which the scanning spot is required to trace.

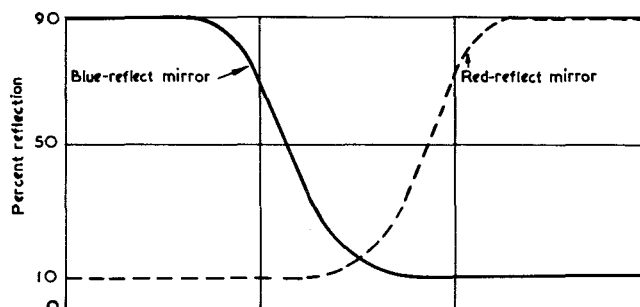
(a)
Spectral emission of
zinc oxide phosphor



(b)
Signal current of
photomultipliers



(c)
Reflection characteristics
of dichroic mirrors



(d)
Spectral emission of
average receiver

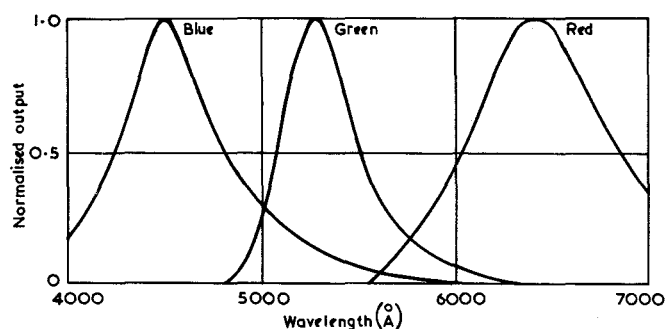


Fig. 4

The modulated light from the film is divided into its red, green and blue components by two dichroic mirrors set at 45° to the optical axis (see Fig. 5). The first mirror is so constructed that it reflects red light but transmits green and blue, while the second mirror reflects blue and transmits the residue, which is the green component. The reflection characteristics of these mirrors* are shown in

*From requirements computed by W.N. Sproson

Fig. 4(c). Since the absorption of a dichroic mirror is very small, the light transmission characteristics may be taken to be the inverse of these curves, so that division of the light is performed with very little loss and each photomultiplier sees only light of the appropriate wavelengths.

The shape of the analysis characteristic in each channel is finally determined by a "shaping filter" interposed between the dichroic mirrors and each photomultiplier to give the required overall transmission characteristic, which is, in turn, determined by the spectral characteristics of the receiver upon which the signals will eventually be displayed. The spectral characteristics of suitable phosphors to produce red, green and blue separation images in the receiver are known, Fig. 4(d), and in the same way that present monochrome transmission standards assume the "gamma" of receiver cathode-ray tubes to be approximately 2.5, so will colour transmission standards be obliged to assume also certain chromaticities in the average colour television receiver.

3. THE COMPLETE SCANNER.

3.1. Specification.

From the foregoing considerations, an outline specification for the machine can be stated, and on this basis the complete film and slide scanner has been designed:

- a. Motion pictures from 16mm film using an intermittent mechanism. Pulldown time to be as short as possible but not necessarily within the frame suppression period.
- b. Provision to be made for scanning large slides to give alternative still pictures of good signal-to-noise ratio.
- c. The scanning raster to be as small as possible commensurate with spot size and phosphor saturation.
- d. Equalisation for aperture losses to be commensurate with a tolerable signal-to-noise ratio.
- e. Colour analysis characteristics to be such that the full range of chromaticities possible in the receiver is fully exploited, with acceptable accuracy.

3.2. Optical Arrangements.

Fig. 5 is a diagram of the optical layout adopted for the machine and shows the alternative light paths for film or slide scanning. In this arrangement the same flying-spot tube and photocells are used in either application.

A three-position turret carries a mirror set at 45° to the optical axis and also two lenses of different focal lengths. When the turret has been rotated to bring the mirror into position, the flying-spot raster is imaged by lens 3 upon the film in the gate of the intermittent mechanism. The focal length of the lens and the conjugate foci are chosen so that the 16 mm frame is filled precisely ($m \simeq \frac{1}{8}$).

After passing through the film and so becoming modulated in colour and intensity, the light is collected by a condenser system and passed into the colour-analysis unit.

The focal lengths for the lens and condenser system and the distance from film plane to photocell surface have to be computed with some care since two stringent requirements have to be met. The first is that the angle of incidence of any light ray to the dichroic mirrors shall be as constant as possible. This is because the reflection/transmission characteristic of a dichroic mirror varies with the angle of incidence, and if in scanning from top to bottom of the film frame this angle changes significantly the result will be a colour "frame-tilt" down the picture. The angle can, of course, only remain constant if the lens is of infinite focal length but material advantage can be gained by using lenses of several times the normal focal length for the image size required.

The second requirement is that as the flying-spot scans the film frame the distribution of light over the photocell surface shall not change. Photocells are not as a rule of uniform sensitivity over their sensitive surfaces and if the light falling upon them tends to scan the surface as the film frame is scanned, areas of incorrect level may be produced in the picture. This difficulty may be overcome by arranging the focal length of the condenser system so that the rear nodal plane of the lens is imaged in the planes of the photosensitive surfaces. The space essentially occupied by the dichroic mirrors may however make it very difficult to achieve correct imaging with the degree of magnification required to fill, but not spill over, the working area of the photocathode.

In the colour analysis unit the red and blue light paths, after separation by the dichroic mirrors, are folded by insertion of surface-aluminised mirrors so that the three photomultipliers lie parallel to each other in a compact arrangement. The shaping filters are mounted directly in front of the photocathodes and adjustment is provided in the supports for the photomultipliers to take up dimensional differences and to permit accurate positioning in the focal plane of the condenser system. The whole assembly of mirrors, photomultipliers and their associated head amplifiers is housed in a light-tight box which is so hinged that it may be turned over to the alternative position for slide scanning, when the optical path then becomes a straight line from the scanning tube.

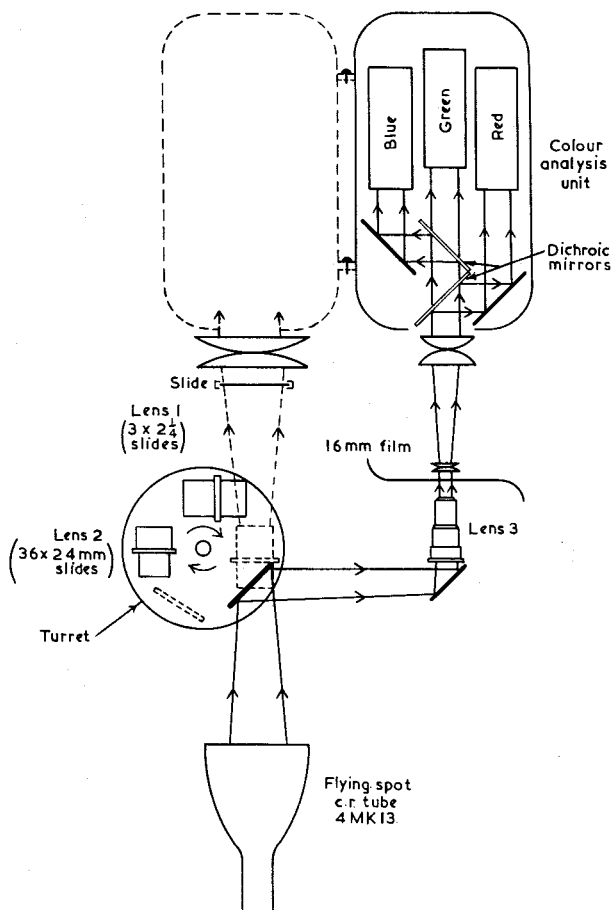


Fig. 5 - Optical arrangement

If the longer focal length lens is selected by rotation of the turret, the raster is imaged in the plane of the slide-carrier at unity magnification and 3 in. \times 2 $\frac{1}{4}$ in. (7.6 cm \times 5.7 cm) colour transparencies may be scanned. Modulated light from the slide is collected by the condenser whose focal length is again chosen to image the rear nodal plane of the lens at the cathodes of the three photomultipliers.

If the shorter focal length lens is selected the raster is imaged approximately half-size and is suitable for scanning "Leica-size" transparencies; the lens-to-slide distance in this case is less than that of the larger slides and it is therefore desirable to change the focal length of the condenser, but this facility has not so far been incorporated and a certain amount of light is lost due to spill-over at the photocathodes. As a result there is a loss of signal-to-noise ratio when scanning this particular slide size, but the amount of spill-over does not change during the scan and no undesirable shading effects are produced.

It will be noted from Fig. 5 that the positioning of the optical components and the separation of the alternative light paths are determined precisely by the magnifications required and the focal lengths chosen for the 16 mm system and one of the two slide sizes. To add the second size of slide would call for a lens of very precise focal length and mechanical dimensions to image the raster in the correct plane. This difficulty was overcome by selecting the nearest available focal length lens to that determined by calculation and then taking up the small difference in the sum of the conjugate distances by making the slide adaptor (3 $\frac{1}{4}$ in. \times 3 $\frac{1}{4}$ in. [8.3 cm \times 8.3 cm] to 2 in. \times 2 in. [5.1 cm \times 5.1 cm]) suitably recessed to bring the latter size into the correct plane for focus at the required magnification.

Each of the three lenses is fitted with a helical focusing mount for fine adjustments and the flying-spot tube is also adjustable along the optical axis over small limits.

3.3. Mechanical Arrangements.

The whole of the film and slide scanning assembly is mounted on a stout channel-iron frame which is made the full size (68 in. \times 30 in. [172.7 cm \times 76.2 cm]) of the right-hand bay in Fig. 6. The frame was planed after construction and strips of $\frac{1}{2}$ in. (1.3 cm) gauge-plate are bolted across the front faces of the frame in each position where fixings for the various optical components are required.

The 16 mm film transport mechanism is a modified GB-Bell and Howell model 609 projector and is mounted so that the optical axis is vertical. The normal motor drive supplied with the mechanism has not been used since it is of course necessary that the mechanism should be operated in synchronism with the television field pulses. A suitable spindle in the mechanism, operating at one revolution per frame, has been coupled to a four-pole single-phase synchronous induction motor which is powered by a push-pull amplifier producing 230 V 50 c/s derived from the field synchronising pulses. A variable phase shift is provided in the motor drive amplifier so that the pulldown of the film may be correctly phased with respect to the field scan of the television system. The normal 1500 rev/min motor may pull in to any of four possible positions when in synchronism. Whereas two of these 180° apart may be phased to coincide with a field suppression period, the other two positions give a bar across the middle of

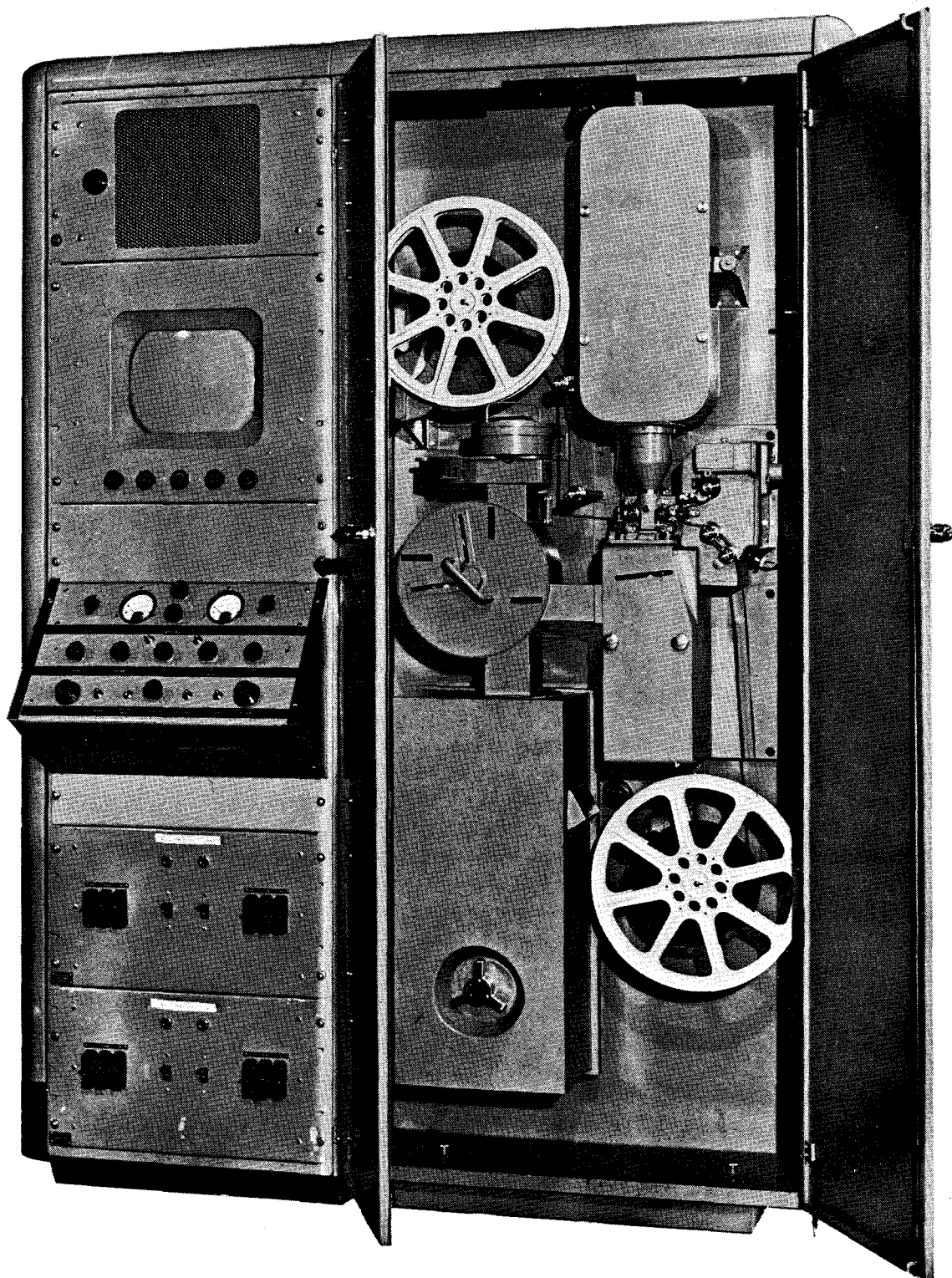


Fig. 6 - Mechanical layout

the picture due to pulldown taking place about the midpoint of the field scan. To overcome this ambiguity a polarised motor is being fitted which will have only two possible pull-in positions, so that once the phase of the motor supply has been set, no further adjustments on re-starting should be necessary. No drift of pulldown phase is experienced, probably because the film take-up spool is driven by a separate motor through a slipping-belt mechanism, and the load on the main motor remains constant.

The flying-spot tube is mounted in an adjustable cradle together with its associated focus and deflector coils, so that in adjusting the position of the raster with respect to the optical system, the relative positions of tube and coils are not disturbed. The tube assembly is encased in a lead box to preclude any danger from the soft X-rays which are generated when operating at anode potentials in excess of 25 kV.

Care has been taken to prevent any extraneous light from entering the light paths of the apparatus, and metal trunking connects the various optical elements of the apparatus. A two-position slide carrier is provided so that a rapid change can be made from one slide to another, while a microswitch coupled to the operating lever of this device blacks-out the picture during the changeover.

3.4. Electronic Circuits.

The circuits comprising a complete colour film scanner nominally include all the apparatus required to produce three colour separation signals, each afterglow and aperture corrected and having a contrast law approximately of the form, $\gamma = 0.4$. The correction and gamma control circuits form the bulk of the electronic apparatus and a detailed description of them will be the subject of a separate report. The circuit arrangement required to produce three uncorrected colour separation signals is however indicated by the schematic diagram in Fig. 7.

In accordance with usual practice, line and field timing pulses from the master synchronising pulse generator are used to control the operating cycle of the scanner. The scanning generators, flyback suppression, and motor drive to the intermittent mechanism are all synchronised by these master pulses while a variable delay in the line timing pulse permits accurate adjustment of the timing of outgoing video signals.

The flying-spot cathode-ray tube is of an experimental type specially constructed for colour scanning and at present uses a simple zinc-oxide phosphor; it has an overall diameter of 5 in. (12.7 cm) and is normally operated at 27 kV anode potential with beam current of 100 to 150 microamperes. The anode potential is provided by an r.f. oscillator power supply, accurately stabilised and adjustable in output voltage. Toroidal deflector coils, together with a high quality electromagnetic focus assembly, are used to obtain the best possible field of focus on the raster.

The video circuits in this part of the apparatus are extremely simple. The three photomultipliers handling the red, green and blue signals each have an associated single stage amplifier in the colour analysis unit feeding the three signals to the main video amplifiers, and these in turn pass the signals via output distribution amplifiers to the video signal correction circuits. The main video amplifiers

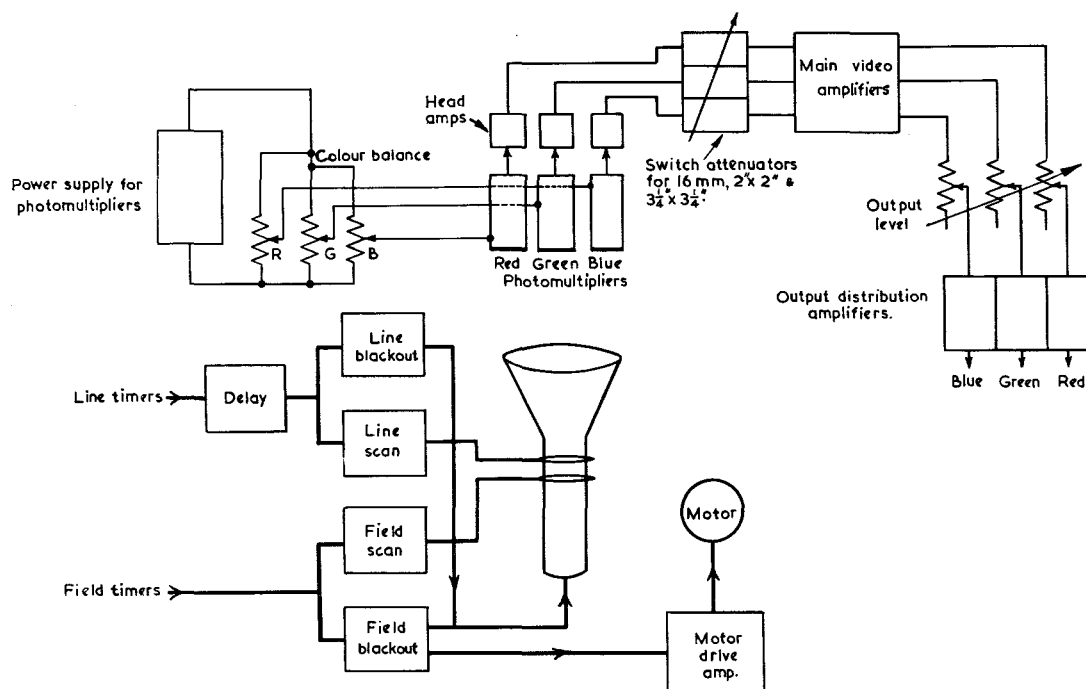


Fig. 7 - Electronic arrangements

incorporate three matched and ganged attenuators to compensate the change of signal level when the slide size is changed.

Since the light output of the flying spot tube is not uniform over the spectrum and the sensitivities of the photomultipliers are not equal, some difference in the gain of the three multipliers may be necessary to achieve the desired balance between the three signals. Primary colour balance is carried out by variation of the dynode potentials of the three photomultipliers until the amplitudes of the signals in the red, green and blue channels are equal when the subject matter is a neutral grey based upon the colour temperature chosen to give the most satisfactory colour reproduction.

Control of the output level of the three signals after balancing cannot successfully be obtained by variation of the common supply to the dynodes since the gain of a photomultiplier is not linear with potential, and therefore in addition to the compensating attenuators in the main video amplifier, a three-gang $75\ \Omega$ potentiometer is placed at the inputs to the distribution amplifiers and is used to take up the smaller variations in signal level due to changes of density in the subject matter.

Colour balance and output level adjustments are carried out with the aid of a waveform monitor, but a 10 in. (25.4 cm) black-and-white picture monitor is included in the apparatus to enable the operator to check pulldown phase, framing and focus, and this monitor is provided with a selector switch at the input so that each of the colour separation signals may be examined in turn.

4. PERFORMANCE AND FUTURE IMPROVEMENTS.

In reviewing the performance of a colour television film scanner, it is inevitable that the signal-to-noise ratio should be found to be the feature most needing improvement, since other parameters of picture quality may be improved if a good signal-to-noise ratio is available. With the components at present available, the signal-to-noise ratio on a 16 mm colour scanner is hardly satisfactory, but the use of large slides does provide a comparatively noise-free picture.

The measured performance at present available from the scanner under conditions of optimum equalisation is as follows:

Signal-to-Noise Ratio (Peak Signal to r.m.s. Noise)			
Subject Matter	Red Channel	Green Channel	Blue Channel
$2\frac{1}{4}$ in. \times 3 in. (5.7 cm \times 7.6 cm) (f/3 lens)	34 dB	35 dB	35 dB
24 mm \times 36 mm (f/3 lens)	29 dB	30 dB	31 dB
16 mm film (f/1.6 lens)	25 dB	26 dB	26 dB

The measured ratios on 24 mm \times 36 mm slides are about 2 dB lower than would be expected from calculation of the relative sensitivities of the three image areas: this is due to the "spill-over" of light at the photo-cathodes, mentioned in Section 3.2, but the 16 mm light path is subject to very little loss and an improvement can only come with the introduction of new components. With well-designed video circuits even the low level, high frequency, components of the output signal from the photo-multipliers can be kept at a level substantially above valve noise, and it can therefore be stated that all the visible noise accompanying the signal is due to inadequate photo-current. Improvements will therefore be effected by:

- a. A better ratio of modulated to unmodulated light falling on the photo-cathodes.
- b. A greater absolute value of light.
- c. A greater sensitivity in the photo-cathodes.

Requirement (a) could be met by a reduction in the afterglow time of the flying-spot scanning tube, and also by reductions in halation and flare in the tube face-plate and the lenses, while (b) calls for a tube having a uniform spectral distribution of light output, a phosphor of very fine grain structure and a smaller scanning-spot size to permit a smaller raster to be used. It is, of course, obvious that larger lens apertures and increased brightness of the raster would be of direct benefit provided they could be obtained without a counterbalancing loss of resolution.

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